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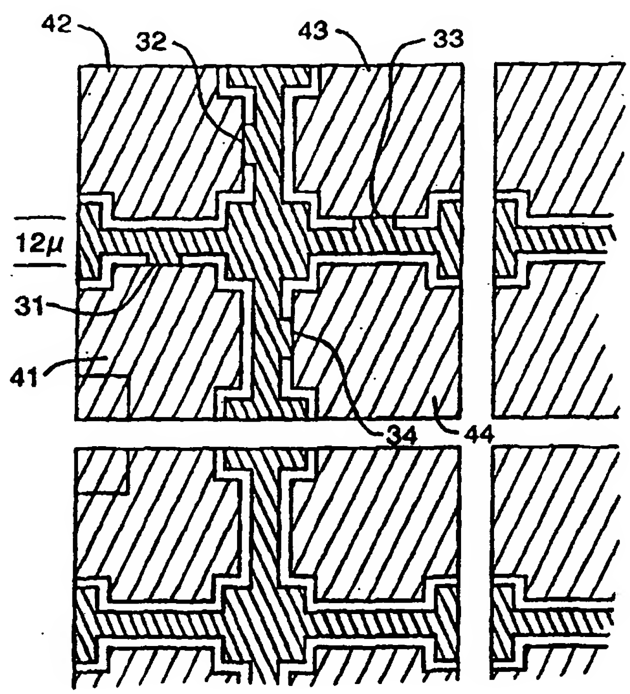
(54) Title: METHOD FOR IMPROVING THE YIELD OF AN IMAGE SENSOR

(57) Abstract

A method is provided that increases the manufacturing yield of semiconductor and liquid crystal devices comprising at least one defined region. The defined region is subdivided into a plurality of sub–regions, which are electrically connected in parallel. If a defect is present in the defined region, it makes only one or more sub–regions inoperable, while the remaining sub–regions function. The functioning sub–regions are combined and their outputs normalized so that the output of the defined region is unchanged, as if the sub–region effected by the defect did not exist.



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METHOD FOR IMPROVING THE YIELD OF AN IMAGE SENSOR

This invention in general relates to the fabrication of devices comprising arrays of semiconductor imaging pixels or liquid crystal cells and, more particularly, to a method for improving the fabrication yield of such arrays.

More particularly, the invention relates to an apparatus and method for improving yield of devices having defined regions therein where manufacturing of such semiconductors with defined regions experiences an overall decrease in yield which is directly related to the surface area of the defined region.

There are numerous commercially available devices that require defined regions disposed therein. Examples of such devices are liquid crystal displays ("LCD") and image sensors, such as charged coupled devices ("CCD"), charged injection devices ("CID") and CMOS image sensors. Defects in the semiconductor crystalline material are common in the semiconductor fabrication industry. Often, such defects are point defects that are of the one micrometer size or less. Generally, a threshold number of such defects is determined and any semiconductor device that has a number of defects in excess of the threshold number is deemed unusable.

Defects which prevents proper operation of a defined region, commonly referred to as "killer" defects, occur at random over the surface of such semiconductor devices. As the surface area of a defined region for a semiconductor device is increased, the probability of that such a killer defect will be found within that defined region increases proportionately.

Often in such semiconductor devices that incorporate defined regions, larger defined regions may be desired. In way of example, for an optical component, the larger the defined region, the greater the light capturing or transmitting properties. Each of those defined regions defines a pixel and each larger pixel then has increased sensitivity in low light applications. As can be appreciated by one skilled in the art, semiconductor devices comprising large defined regions have an extremely low fabrication yield and, accordingly, a proportionally higher manufacturing cost.

Referring now to Figure 1, there is shown a prior art semiconductor device 10 comprising a defined region 12. Defined region 12 comprises vertical delimiters 16 and horizontal delimiters 18 by which defined region 12 has a predetermined length (L) and a predetermined width (W). If a defect 14 is present within defined region 12,

semiconductor device 10 may not function properly. It is an object of this invention to provide a method for increasing the yield of semiconductor devices comprising defined regions.

It is another object of this invention to increase the number of usable pixels within a semiconductor device operating as an optical element.

Other objects of the invention will be obvious, in part, and, in part, will become apparent when reading the detailed description to follow.

The aforementioned and other objects are achieved by a method which comprises the steps of subdividing and electrically reconnecting defined regions on the semiconductor device. The number of such sub-regions are determined by the particular application of the device. For an LCD, a particular region or pixel may be divided into two electrically-connected sub-regions such that control signals flow to both sub-regions to make the two sub-regions operate as a single cell. The output signal of the sub-regions is normalized to offset the effects of a defective sub-region. For example, if a region of a CCD is divided into four sub-regions one of which contains has a defect, the combined output of the three functioning sub-regions is amplified by a factor of four-thirds.

Other features of the invention will be readily apparent when the following detailed description is read in connection with the drawings.

The structure and operation of the invention, together with other objects and advantages thereof, may best be understood by reading the detailed description to follow in connection with the drawings in which unique reference numerals have been used throughout for each part and wherein:

Fig. 1 is a conventional semiconductor device comprising defined regions;

Fig. 2 shows a semiconductor device where defined regions are vertically subdivided into two sub-regions, in accordance with the present invention;

Fig. 3 is a diagrammatical view of a semiconductor device having defined regions subdivided in accordance with the present invention, showing fusible links interconnecting the sub-regions;

Fig. 4 is a schematic diagram illustrating removal of a sub-region from the defined region of a semiconductor device;

Fig. 5 shows a semiconductor device having defined regions vertically divided into three sub-regions;

Fig. 6 shows a semiconductor device having defined regions horizontally divided into two sub-regions; and

Fig. 7 shows a semiconductor device having defined regions horizontally and vertically divided into four sub-regions.

While the present invention retains utility within a wide variety of semiconductor devices and may be embodied in several different forms, it is advantageously employed in connection with semiconductor devices used as opto-electronic elements such as CCDs and LCDs. Although this is the form of the preferred embodiment and will be described as such, this embodiment should be considered illustrative and not restrictive.

There is shown in Fig. 2 a semiconductor device 20 comprising a plurality of defined regions 21 of size 'L' by 'W.' Semiconductor device 20 may comprise an LCD, or an image sensor such as a CCD or a CID, for example. Each defined region 21 is bounded by a pair of vertical delimiters 26 and a pair of horizontal delimiters 28. A sub-divider 22 subdivides defined region 21 into sub-regions 24, each sub-region 24 having dimensions of approximately L/2 and a width of W. Sub-divider 22 can be fabricated by the same processes used to fabricate vertical delimiter 26.

Sub-regions 24 are electrically joined, as described in greater detail below, such that all sub-regions 24 communicate with the same electrical signal provided to the corresponding semiconductor device 20. When a defect 29 is present in one sub-region 24, defined region 21 will continue to function by means of one or more other sub-regions 24. By way of example, a single external signal transmitted to an individual cell of an LCD will modulate both sub-cells, and provide an output even if one sub-cell contains a defect. This technique has the further advantage of being fully compatible with the manufacturing process sequence used with devices not having redundancy. The benefit is then one of cost and simplicity.

To provide for uniform operation of each defined region 21, the output signal is normalized. If one of a pair of sub-regions 24 is defective (i.e., one half of the region is non-operative), the signal from the defined corresponding defined region 21 will, accordingly, be attenuated by a factor of two. To compensate for this, the attenuated output of defined region 21 is amplified by a factor of two, that is, the reciprocal of

the non-defective portion of defined region 21. Thus, all defined regions 21 are normalized to a uniform output so as to decrease the effects on an output signal.

The improvement realized by this method can be illustrated by means of statistical analysis performed upon an image sensor device approximately 1 cm^2 in area comprising about 1 million pixels, each pixel having a dimension 6 μm × 12 μm. Assume a target fabrication yield for these image sensors of twenty percent (20%), with the criterion that an image sensor is functional with one hundred or fewer killer defects. The defect distribution would be substantially Gaussian with a mean of n=109 and with twenty percent of this distribution lying below 100 (meaning that 20% of the chips have fewer than 100 defects). This can be stated mathematically as:

$$n = 109.0$$

$$\text{std} = \sqrt{n}$$

$$P = \text{cnorm}\left(\frac{100.0 - n}{\sqrt{n}}\right)$$

$$P = 0.194$$

where the function "cnorm" denotes the normal distribution function. The defect density, D, is then $109/cm^2$.

A second example is an image sensor for use in medical X-ray applications. Such an image sensor may be 60 mm × 80 mm, or 48 cm^2, with 10^6 pixels, each pixel having an area of:

$$A = 48.0\ cm^2 / 10^6 = 4.8 \times 10^{-9}\ m^2$$

The probability, P1, that a given pixel is unusable due to a killer defect is then

$$P1 = A \times D = (4.8 \times 10^{-9}\ m^2)\ (109\ cm^{-2}).$$

For an image sensor comprising 10^6 pixels, the mean number of defects is given by:

$$n = 10^6 \times P1 = 5.232 \times 10^3$$

This is an undesirable value. If the acceptable number of defects per image sensor remains at one hundred, the yield, Y, goes to zero.

$$Y = \text{cnorm}\left(\frac{100.0 - n}{\sqrt{n}}\right) \approx 0$$

The inventive method divides each pixel into sub-pixels, for redundancy, and bypasses the unusable sub-pixels. Although relatively large pixels can be subdivided into more than two sub-pixels, it has been determined that a single subdivision is

adequate. For example, if each pixel is subdivided into two sub-pixels, then the probability P1 of an unusable sub-pixel is:

$$\frac{P1}{2.0} = 0.0026$$

The probability P2 that both sub-pixels are unusable is:

$$P2 = (\frac{P1}{2.0})^2 = 6.843 \text{ x } 10^{-6}$$

If a pixel is defined as functional if at least one of its sub-pixels is operating, then the mean number of unusable pixels in the image sensor now decrease to:

$$n = 10^6 \times P2 = 6.843$$

This means that, for a threshold of 100 defective pixels, this criterion would result in a nearly one hundred percent yield.

$$Y = cnorm\, \frac{100.0 - n}{\sqrt{n}} \approx 1$$

The return diminishes, however, by increasing the number of sub-pixels. For example, if the image sensor of the above example is divided by two along each dimension (as is shown in Figure 5 discussed below), there are now four sub-pixels per pixel rather than two. The probability P4 that a given sub-pixel is unusable is found to be:

$$P4 = \frac{P1}{4.0} = 0.001$$

For such an image sensor, the probability for defects in a pixels are as follows:

Unusable Sub-Pixels	Probability
None	$a = (1.0 - P4)^4 = 0.995$
1	$b. = 4 \times (1.0 - P4)^3 \times P4 = 0.005$
2	$c = 6 \times (1.0 - P4)^2 \times P4^2 = 1.024 \text{ x } 10^{-5}$
3	$d = 4 \times (1.0 - P4) \times P4^3 = 8.94 \text{ x } 10^{-9}$
4	$e = P4 \times 4 = 2.927 \text{ x } 10^{-12}$

where $a + b + c + d + e = 1$

Based upon this analysis, it is unlikely that more than one unusable sub-pixel will be situated in a given pixel. This provides flexibility in determining criteria for usable pixels.

Criterion #1: A pixel is usable if it has at least three functional sub-pixels. probability, $P4_3$, of a unusable pixel is:

$$P4_3 = c + d + e = 1.025 \times 10^{-5}$$

The mean number of unusable pixels per image sensor is:

$$n = 10^6 \times P4_3 = 10.247$$

This criterion requires at least three-quarters of the pixel area for each usable pixel. In addition, a threshold of 100 defects for a usable image sensor still gives effectively one hundred percent yield.

$$Y = \text{cnorm}\left(\frac{100.0 - n}{\sqrt{n}}\right) \approx 1$$

Criterion #2: A pixel is usable if it has at least two functional sub-pixels. The probability, $P4_2$, of a unusable pixel is:

$$P4_2 = d + e = 8.942 \times 10^{-9}$$

The mean number of unusable pixels per image sensor is:

$$n = 10^{-6} \times P4_2 = 0.009$$

This criterion requires at least one-half of the pixel area for each pixel is usable, and essentially ensures no unusable pixels. This is, indeed, a somewhat better image sensor than the previous case, at the expense of another factor of two in the number of pixels which must be manipulated. Moreover, this example makes it clear that further divisions are not necessary.

Further, since the sub-pixels are still rather large, and the exposure times are generally long (roughly a second or 2 for a mammogram), it is possible to wire this image sensor as a two million or four million pixel CCD (or CID), and read it out in a conventional way. Other wiring schemes are feasible if the number of sub-pixels are kept small. The chosen wiring should be adapted to the nature of the defects.

Fig. 3 shows an embodiment of the invention where fusible links 31, 32, 33, and 34 are used to isolate defective sub-image regions 41, 42, 43. and 44 respectively. During device test, defective regions, usually shorted regions, are identified, and by using current pulses or laser beams, fusible links are activated and designated regions are programmed out of the image sensor array. This technique applies to CMOS, CCD, and CID technologies.

Fig. 4 shows an embodiment of the invention wherein a self-correcting pixel design is used to dynamically identify and remove a defective sub-image region 49. A simple fusible link in series with each sub-image region will be opened as a result of the abnormally large currents that will exist at shorted sites. If sub-image regions subsequently become defective, this technique will automatically identify and eliminate them. Non-responsive defective pixels will not be removed, but they do not contribute to the output. This technique applies to CMOS image sensors.

For the case of CCD imaging the above analysis has assumed that charge can be shifted through defective sites. If however, charge cannot be shifted column wise through the defective sites (column defect), another probability analysis can be done. In addition, each quadrant of a pixel may then be wired as part of a separate one-million pixel image sensor so that there would be four such image sensors interleaved. With this wiring, any column defect would be restricted to a single sub-image, the advantage of which is described more fully hereafter.

Figure 5 shows a second embodiment of the invention where a one-third sub-divider 51 and a two-thirds sub-divider 52 are vertically disposed on a semiconductor 50. A defined region 53 is then broken into three sub-regions 56 each having a length of L/3 and a width of W. In this way, a defect 59 within sub-region 56 further reduces the effect of defect 59 on defined region 53. By decreasing the size of a sub-region, the effect of a defect on yield becomes statistically reduced, as discussed above.

The number of subdivisions must be determined in view of each of sub-dividers 51 and 52 having a finite width where the overall size of defined regions 53 in practice are less than L/3. The actual amount less is going to depend upon the implementation and the semiconductor device 50 itself. For example, in the case of a CCD, sub-dividers 51 and 52, as well as vertical delimiter 55 and horizontal delimiter 57, include electronics and channel stops between light wells. In order to perform the function of a channel stop there must be a fairly significant impediment to intercommunication between wells formed by the channel stops. Thus, each of these channel stops can have a width on the order of approximately 1.0 micron. Given for example a typical length for a CCD cell being 50 microns the addition of these two channel stops then constitutes approximately a 2 percent decrease in light accumulation capabilities. Therefore, each application will find its own balance where the number of sub-dividers must be balanced against the detrimental effects on the device.

In the case of CCD, the preferred embodiment comprises horizontal sub-dividers as shown in Fig. 4. A semiconductor device 60 comprises a horizontal sub-divider 62 that divides a defined region 61 into sub-regions 64. The orientation of sub-dividers 62 depends upon the particular application. In the illustration, horizontal sub-divider 62 subdivides defined region 61 into sub-regions 64 having a length L and a width W/2.

While in some applications such horizontal subdivisions may be appropriate, in the case of CCDs, the preferred method is to subdivide the semiconductor device perpendicular to the shift direction as shown in Figure 2 and Figure 5, for example. The effect on isolated pixel defects is the same as if the pixels is divided along both directions, but the effect on shifting defects is dramatically different.

For example, taking the image sensor having dimensions previously described with about 5000 defects and assuming that ten percent of these are column defects, then there are 500 column defects, on average, in 1000 columns. Each column has a fifty percent chance of having a defect. The image sensor is less than optimal and would likely be deemed unusable.

In contrast, if each column is divided into two sub-columns, each of which has a twenty-five percent chance of a column defect, then the probabilities for a column-pair are as follows:

Both defective	P = 0.07
One defective	P = 0.38
None defective	P = 0.55

In this case, if the criteria for determining usability is that at least one sub-columns is usable, then there is a seven percent chance of a unusable column. The mean number of unusable columns has then been reduced from 500 to 70.

If each column is divided into four sub-columns, each of which has a twelve and one half percent chance of a column defect, the probabilities are:

Four defective	P = 0.0002
Three defective	P = 0.0068
Two defective	P = 0.072
One defective	P = 0.335
None defective	P = 0.586

In this case, if the criterion for calling a column usable is that at least two of its sub-columns are usable, then there is approximately 0.79% chance of a unusable

column. The mean number of unusable columns has then been reduced from 70 to approximately 8. As previously noted, this level of subdivision provides image sensors without appreciable isolated pixel defects.

If the pixel were divided by four in the other direction, the effect on isolated pixel defects would be substantially the same, but there would be four times as many shifts required for each column, and the number of column defects would be the same as if no subdivision of columns had taken place.

Figure 7 shows a semiconductor device 70 subdivided by a sub-divider 72 in a vertical direction and a sub-divider 74 in a horizontal direction. The subdivisions then create sub-regions 73 each having a length L/2 and a width W/2. This construction provides quadruple redundancy such that a defect 79 acts to only make inoperable one-fourth of a defined region 72. The output or input of defined region 72 is then normalized by multiplying each operable sub-region 72 by four-thirds, thus normalizing the cell as compared to its neighbors.

If multiple defects occur within an individual defined region 72, then this orientation of sub-dividers 72 and 74 provides a redundancy to minimize the presence of such defects. For example, if not one, but two or three defects occur each in a sub-region then two or one respectively, operable sub-regions remain. In the case of two defects, the normalization would then be performed to scale the output signal by a factor of two to normalize the defined region as compared with its neighbors. It should be apparent that the normalization of the output signal can be altered to correct for other deficiencies in the image sensor.

There is a practical limitation. Redundancy has less effect when the size of the sub-region becomes smaller than the average size of a defect. At such a size, a single defect can make inoperable two or more sub-regions thereby limiting the effectiveness of the redundancy.

CLAIMS

1. A method for increasing yield of manufacturing semiconductor devices, the semiconductor devices having a plurality of defined regions forming a matrix of the plurality of defined regions, each of the plurality of defined regions being adapted to capture information, the semiconductor device having defects that alter the information captured within at least a portion of the plurality of defined regions, the method comprising the steps of:

subdividing each of the plurality of defined regions into sub-regions; and

electronically connecting the sub-regions within each of the plurality of defined regions such that the information captured by the sub-regions within each of the plurality of defined regions can be combined so as to represent the information captured by each of the plurality of defined regions respectively; and

adjusting the information captured from the sub-regions within each of the plurality of defined regions having at least one defect.

2. A method according to claim 1 wherein the plurality of defined regions are subdivided in at least one direction.

3. A method according to claim 1 wherein the plurality of defined regions are subdivided in at least two substantially orthogonal directions.

4. A method according to claim 1 wherein the plurality of defined regions and the sub-regions are defined in one direction by channel stops.

5. A method according to claim 1 wherein the sub-regions and at least one side of the plurality of defined regions are defined by delimiters.

6. A method according to claim 1 wherein the plurality of defined regions are subdivided in a direction perpendicular to a shift direction of the information captured by the plurality of defined regions.

7. A method according to claim 1 wherein each of the defined regions is adapted to receive an electronic signal and the step of electronically connecting further comprises the step of electrically connection the sub-regions such that in response to receiving the electronic signal for the defined region, the plurality of sub-regions respond in combination as the defined region.

8. A method according to claim 1 wherein the information captured from the sub-regions is normalized.

9. A method for increasing yield of manufacturing semiconductor devices, the semiconductor devices having a plurality of defined regions forming a matrix of the plurality of defined regions, each of the defined regions being adapted to receive electronic signals, the semiconductor device having defects that alter response of at least a portion of the plurality of defined regions that include the defects, the method comprising the steps of:

subdividing each of the plurality of defined regions into sub-regions;

electrically connecting the sub-regions within each of the plurality of defined regions such that in response to receiving one of the electronic signals for the defined region, the plurality of sub-regions respond in combination as the defined region; and

adjusting the output signal of the sub-regions within each of the plurality of defined regions that include at least one of the defects.

10. A method according to claim 9 wherein the plurality of defined regions are subdivided in at least one direction.

11. A method according to claim 9 wherein the plurality of defined regions are subdivided in at least two substantially orthogonal directions.

12. A method according to claim 9 wherein the plurality of defined regions and the sub-regions are defined in one direction by channel stops.

13. A method according to claim 9 wherein the sub-regions and at least one side of the plurality of defined regions are defined by delimiters.

14. A method according to claim 9 wherein each of the defined regions is adapted to capture information and the step of electrically connecting further comprises the step of electrically connecting the sub-regions within each of the plurality of defined regions such that the information captured by the sub-regions within each of the plurality of defined regions can be combined so as to represent the information captured by each of the plurality of defined regions respectively.

15. A method according to claim 9 wherein the response to the electronic signal is normalized.

16. A semiconductor device having horizontal and vertical delimiters that define a plurality of defined regions forming a matrix of the plurality of defined regions, each of the plurality of defined regions adapted to be independently electronically controlled, the semiconductor device comprising:

at least one sub-divider extending in at least one direction across a grouping of defined regions;

a plurality of sub-regions disposed within each defined region defined by the sub-divider and a portion of .the vertical delimiter and the horizontal delimiter such that the each defined region includes more than one sub-region; and

connection means for communicating signals to the defined region that is adapted to establishing communication between sub-regions such that the plurality of sub-regions within each defined region respond to a same one of the signals previously received by the defined region.

17. A method of fabricating an optical device defined by a matrix of cells to increase yield of production, the method comprising:

defining a pixel size for the matrix of cells;

subdividing each of the matrix of cells into a sub-matrix of smaller cells; and

electrically interconnecting the sub-matrix of smaller cells.

18. A method of improving yield of semiconductor devices having defined regions disposed therein where yield decreases as surface area of the defined regions increase, the method comprising the steps of:

subdividing the regions into a plurality of sub-regions; and

electrically connecting the plurality of sub-regions for each region.

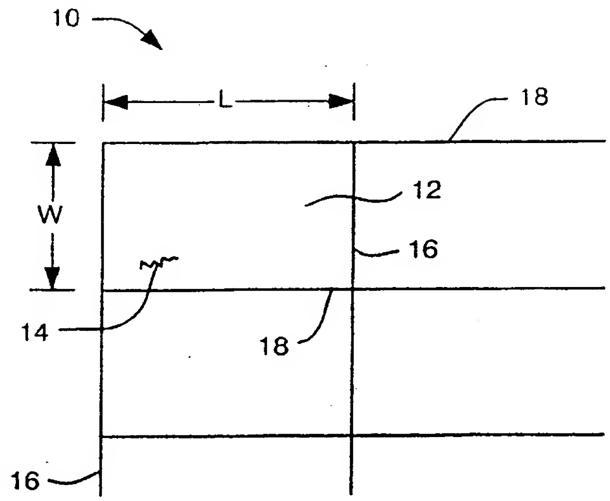

FIG. 1
(PRIOR ART)

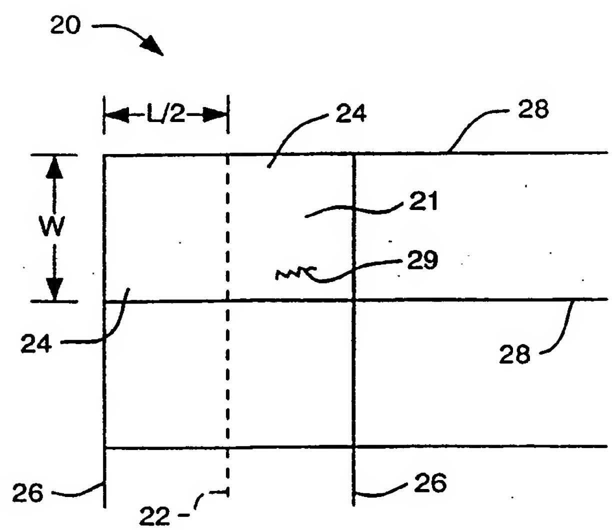

FIG. 2

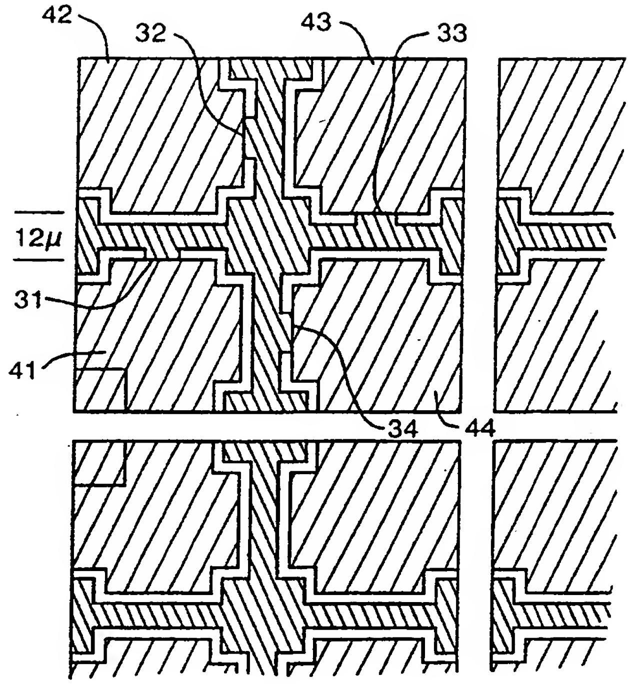

FIG. 3

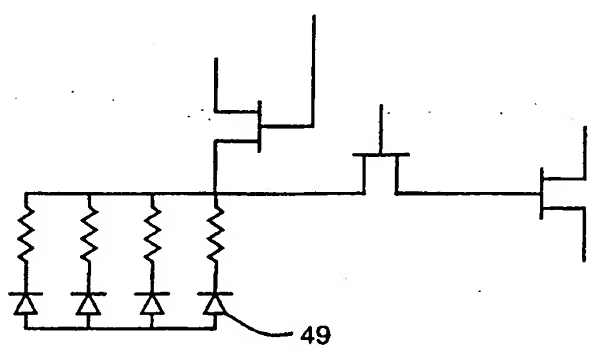

FIG. 4

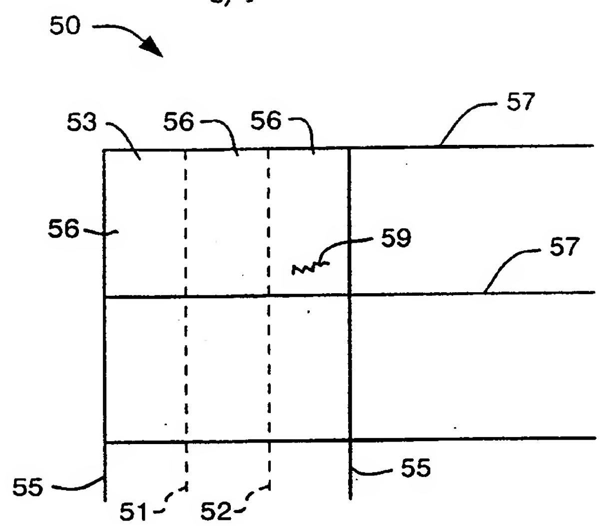

FIG. 5

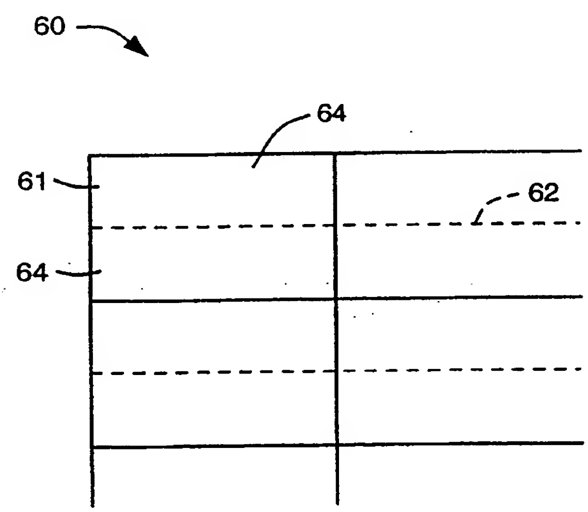

FIG. 6

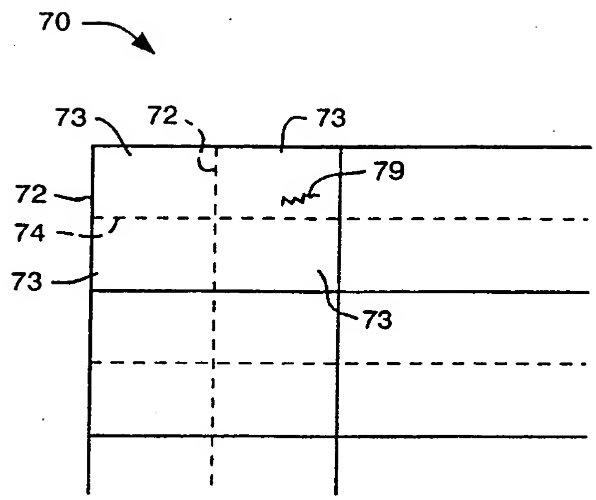

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/23392

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L27/146

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 400 753 A (PHILIPS NV) 5 December 1990 (1990-12-05) column 7, line 42 -column 9, line 3; figures 1,2	1,2,4-7, 9,10, 12-14, 16-18
X	PATENT ABSTRACTS OF JAPAN vol. 015, no. 121 (E-1049), 25 March 1991 (1991-03-25) & JP 03 010472 A (FUJITSU LTD), 18 January 1991 (1991-01-18) abstract	1,9,17, 18
X	US 4 989 060 A (USUI YOSHIKO) 29 January 1991 (1991-01-29) claims 1-5; figure 5	1,2,9, 10,16-18

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[X] Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
11 February 2000	21/02/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Acco, S

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INTERNATIONAL SEARCH REPORT

International Application No
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